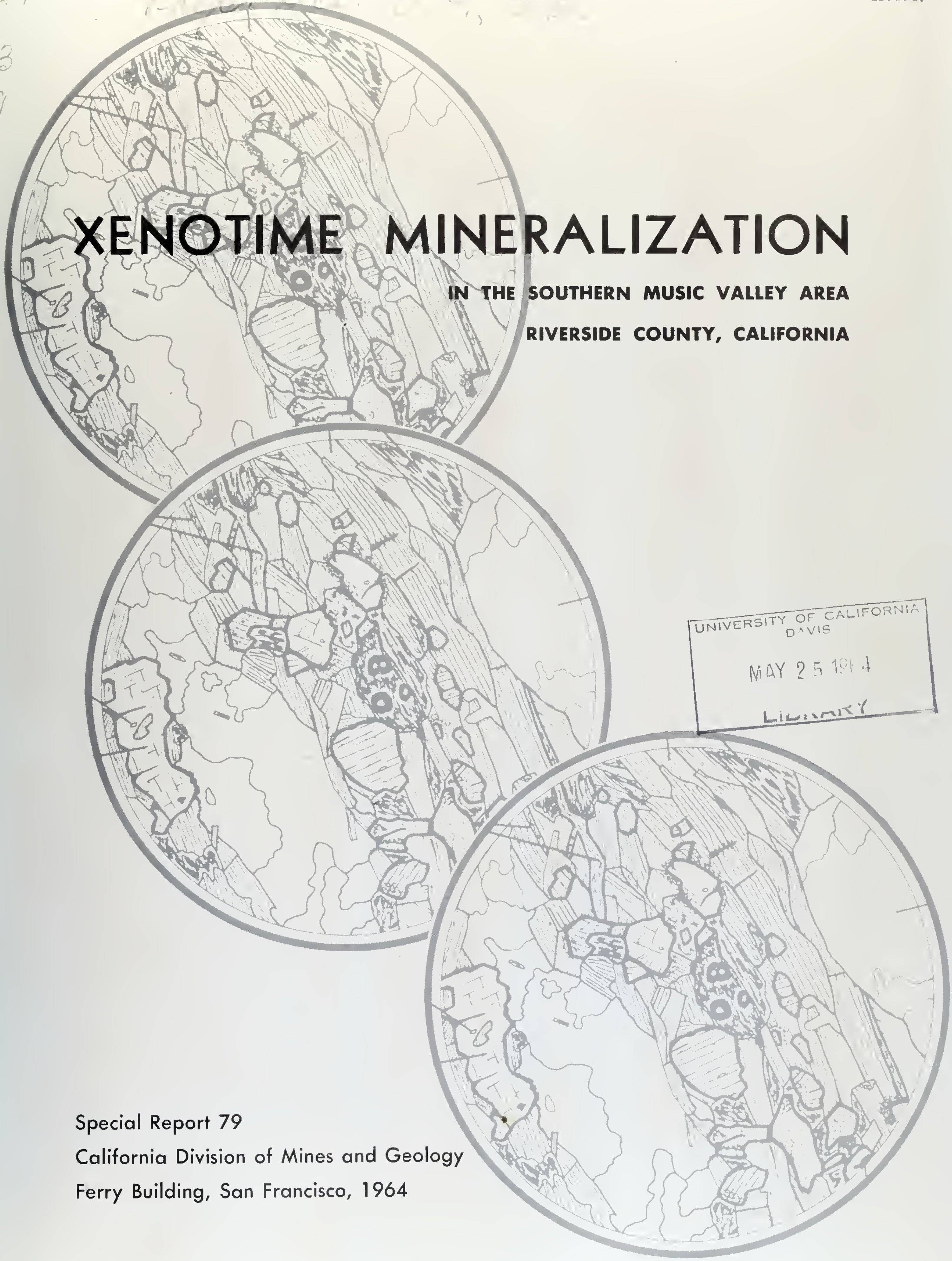

XENOTIME MINERALIZATION

IN THE SOUTHERN MUSIC VALLEY AREA RIVERSIDE COUNTY, CALIFORNIA

Special Report 79
California Division of Mines and Geology
Ferry Building, San Francisco, 1964

XENOTIME MINERALIZATION IN THE SOUTHERN MUSIC VALLEY AREA RIVERSIDE COUNTY, CALIFORNIA

By JAMES R. EVANS, *Geologist*
California Division of Mines and Geology

SPECIAL REPORT 79

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Illustrations

ABSTRACT

Several radioactive rare-earth deposits are known to occur in the north-central desert area of Riverside County, but those in the southern Music Valley by far register the strongest anomalies: as much as 1.7 milliroentgens per hour. In a general way, these deposits occur in a northwest-trending belt about 3 miles wide and 6 miles long.

Radioactivity is a result of the decay of thorium contained in xenotime (YPO_4), and monazite ($CePO_4$). The minerals, irregularly distributed in the Precambrian Pinto Gneiss, are nearly always confined to biotite-rich pods, lenses, and folia. They do occur in quartzo-feldspathic parts of the gneiss, but never in significant concentrations. In the biotite zones, fine to coarse grained crystals of xenotime with minor amounts of monazite are intergrown with oligoclase and quartz. Some potash feldspar, actinolite, muscovite, magnetite, apatite, zircon, sphene, and allanite (?) are also present.

Pinto Gneiss has been intruded by Precambrian (?) Palms Granite and Precambrian Gold Park Gabbro-Diorite which, in this area, consists of hornblende diorite and porphyritic hornblende diorite. Andesitic-basalt dikes, aplite dikes, and veins of milky quartz (of Cretaceous or Tertiary age) occur in all rock types. Older alluvium of Pleistocene age blankets most of the Music Valley, and is composed of coarse, nearly flat-lying, and fairly well-bedded material. Younger alluvium consists of recent stream-laid fill.

Mineralization is not confined to fault zones or to highly faulted areas. It is spatially unrelated to dikes of any composition. Probably the rare-earth mineral concentrations formed early, either before or during metamorphism. As the gneiss appears to be a metasedimentary rock, xenotime and monazite could have been detrital grains in the original sediment, perhaps concentrated locally along bedding planes. These planes would represent zones of relative weakness in which growth and/or migration of the rare-earth minerals could readily have taken place during metamorphism.

A method utilizing the ratio of rare-earth content to radioactivity can be used for roughly estimating part of the mineral reserves. A more precise determination of tonnage and tenor must await further exploration. Xenotime and monazite are amenable to mechanical separation from the gneiss and can be concentrated, after crushing, by gravity and magnetic separation.

The future of these deposits depends largely on the development of new uses for yttrium and its compounds. Current research by the U. S. Bureau of Mines should lead to new applications of yttrium and reduced costs of separating the metal from its sub-group associates, thus creating a new demand for the metal.

XENOTIME MINERALIZATION IN THE SOUTHERN MUSIC VALLEY AREA, RIVERSIDE COUNTY, CALIFORNIA

By James R. Evans

INTRODUCTION

The emphasis given radioactive prospecting by the ground and airborne reconnaissance work of the U. S. Geological Survey in conjunction with the U. S. Atomic Energy Commission in the Live Oak Tank-White Tank areas in Riverside County during 1949 and 1952 (Moxham, 1952) soon led to serious local prospecting and the discovery of radioactive material in the Music Valley area. At first these deposits were thought to contain uranium, but by 1959 no more than traces of uranium had been found, whereas xenotime, the thorium-bearing phosphate of yttrium, was determined to be responsible for most of the radioactivity, and to be the only material of commercial interest. All of the deposits are of a similar nature and occur in the Pinto Gneiss.

Music Valley is about 10 miles southeast of Twenty-nine Palms and 2 miles east of the Gold Park gold mining district, in the Pinto Mountains of San Bernardino and Riverside Counties (figure 1). Wind that frequently blows through the valley and creates a somewhat eerie sound constitutes the "music" for which the valley apparently was named. Of the several radioactive mineral occurrences in this area, those in the southern Music Valley have by far the strongest radioactive anomalies and therefore were studied in detail.

The maximum radioactive anomaly was recorded at the U-Thor deposit, where biotite-rich areas in the Pinto Gneiss contain abundant coarse-grained crystals of orange xenotime and minor amounts of monazite and allanite (?). Such concentrations readily permitted mineral identification, and the study of the type and distribution of mineralization.

Field Work and Acknowledgments

The mineral occurrences were brought to my attention by C. A. Richards, Administrative Geologist, City of Los Angeles, during the course of a study of the mines and mineral resources in the Pinto Basin area of Riverside County. Field work starting in March of 1959 was carried on during April of that year and during July 1960, and consisted of detailed geologic mapping through plane table and Brunton-chain surveys, and general geologic mapping with use of aerial photos. Ground ratioactivity surveys were made with an Engineers Syndicate, Ltd., Model SC-10 scintillation counter used in a grid system. Net radioactivity was then recorded on the grid in milliroentgens per hour (mr/hr), and isorads drawn from these readings.

Completion of this project would have been most difficult without the help of C. H. Gray, Division of Mines and Geology, who assisted with the field work, and critically read the manuscript. In addition, Lauren A. Wright and Oliver E. Bowen, Jr., of the Division staff, and D. F. Hewett, U. S. Geological Survey, Menlo Park, read the manuscript critically, making many helpful suggestions. The cooperation of Wayne E. Chambers, president of the Desert Dominion Mining and Milling Company, Inc., Fontana, California, and Homer Van Dyke, secretary of the Peerless Nuclear Minerals, Inc., Rialto, California, is hereby gratefully acknowledged.

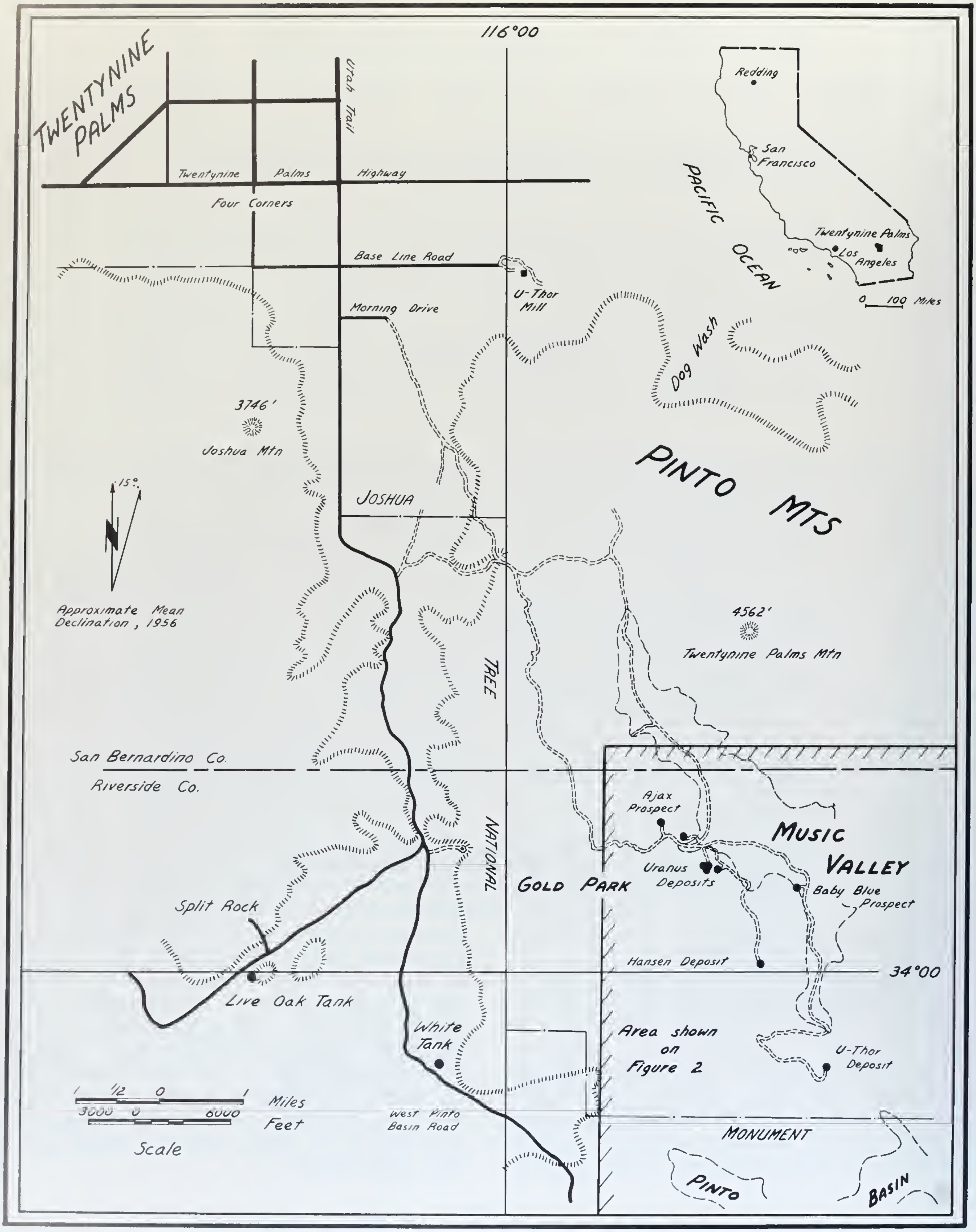


Figure 1. Index maps showing the location of the southern Music Valley area, and distribution of the rare-earth deposits.

GEOLOGY

General Geologic and Structural Features of the Southern Music Valley Area

Most of the area mapped is underlain by much faulted and fractured Pinto Gneiss eroded into low rolling hills with about 500 feet of relief (map 1). A regional structural study of the gneiss was not made, but local studies at mineral deposits, where exposures were excellent, indicate that foliation trends generally west and usually dips between 25 and 60 degrees south. Locally the rock is contorted into both tight and open folds.

The gneiss is the oldest rock exposed, and has been intruded by the Palms Granite and the Gold Park Gabbro-Diorite which here consists of hornblende diorite and porphyritic hornblende diorite phases.

Because the Palms Granite is faintly foliated, and is well coated with desert varnish, it somewhat resembles the Pinto Gneiss in gross aspect. Actually the diorite, except for the porphyritic phase, is difficult to distinguish from the gneiss in areas where relatively small intrusive bodies occur. These rocks can be determined, however, through a study of their microscopic petrography and textures, in detailed mapping of small areas where a variety of rock types occur.

Black to dark green dikes of andesitic-basalt and whitish-gray aplite dikes occur in all the older rock types. Thin veins and pods of milky quartz, locally gold bearing, are common. The dikes and veins are probably Cretaceous or Tertiary in age.

Stratified older alluvium in the southern Music Valley is greatly dissected by intermittent stream courses, a fact which points either to relatively recent uplift of the area or lowering of base level or perhaps both. The entire valley must once have been a closed basin choked with debris derived from the mountains to the north, east, and west. With the change of base level and subsequent increased stream downcutting power, the valley basin was opened at the south end and water, when available, could flow southward into the Pinto Basin (figure 1). The valley extends northwest about 3 miles from the area mapped, and all drainage north of the Uranus 2 deposit is directed northward because of the debris built up in the valley east of the Uranus 2 deposit. Eventually this debris in the central valley will be cut through by headward erosion and all drainage will be to the south (map 1).

Rock Units

Pinto Gneiss

The Pinto Gneiss is probably of Precambrian age and was named by Miller (1938, p. 424) for the widespread and typical occurrence in the Pinto Mountains (figure 1). Rogers, who worked in an area south and west of Twentynine Palms, (1954, Map Sheet 24) reports that the gneiss contains layers of contrasting composition 100 to 500 feet thick. This layering, together with a high content of quartz led him to suggest that the gneiss in this area is largely metasedimentary or metavolcanic and that the layering and foliation are of sedimentary or volcanic origin. Miller indicated

Photo 1. Biotite foliation in the Pinto Gneiss at the U-Thor deposit. The exposure is in a cliff face about 90 feet southeast of the pit.

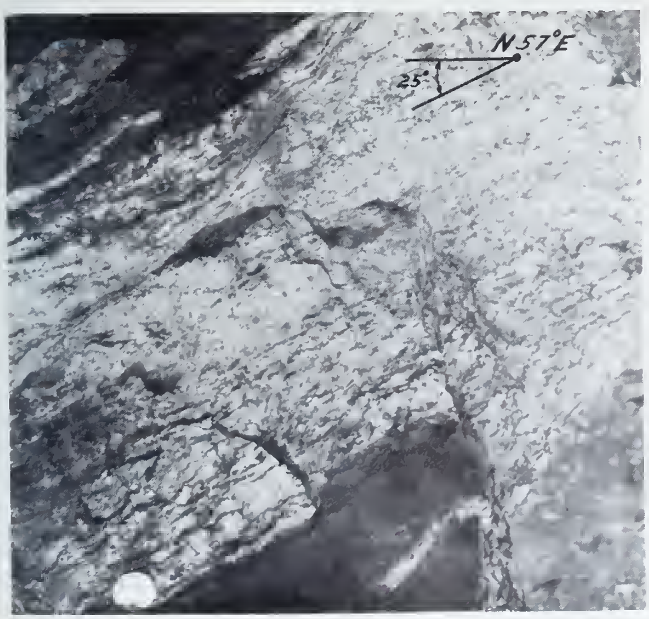
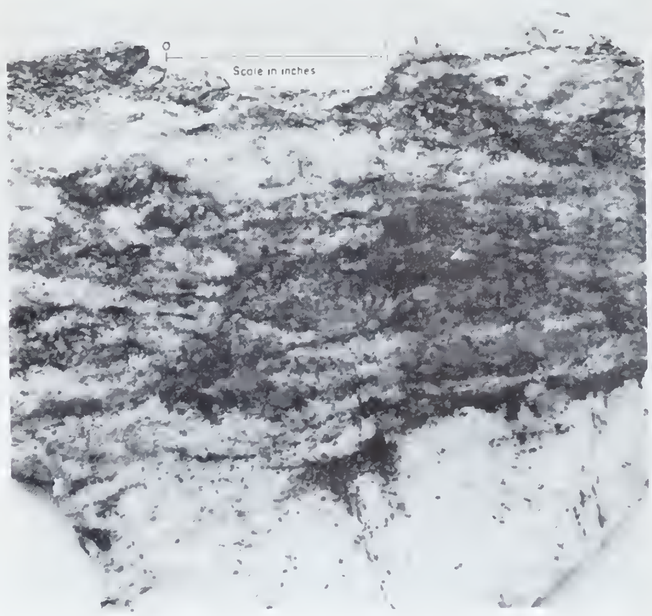


Photo 2. Cut section of Pinto Gneiss from the pit at the U-Thor deposit. Clusters of orange xenotime crystals crowd the biotite folia, and comprise 10-15 percent by volume of the specimen.



that gneiss in the Gold Park area was in part intermixed with granitic rocks, and may have been largely intruded *lit-par-lit* by an acid to intermediate magma. The granitic rock of Miller is undoubtedly the Palms Granite, which here is considered to consist of generally large and discrete intrusive bodies (map 1). Although no compelling evidence was found to prove that the gneiss was once sedimentary and/or volcanic rock, material that was studied pointed most reasonably to such an origin, as has previously been suggested by Rogers.

Typically, the rock shows a thin veneer of brown to black desert varnish, and is weathered to a depth of 1 foot to 3 feet, or perhaps even deeper locally. In gross, the gneiss studied appears to be relatively homogenous, both in general appearance (photos 1, 2) and composition (table 2). The quartzo-feldspathic areas of gneiss are cut by a foliation caused by oriented biotite flakes which may represent original bedding planes. Locally the folia becomes lenses one foot to three feet in longest dimension.

Visual examination shows that the gneiss is composed of nearly equal amounts of quartz and plagioclase feldspar (sodic oligoclase to sodic andesine) with an average biotite content of approximately 35 percent. Locally, biotite zones contain abundant crystals of xenotime; 10-15 percent is not uncommon (photo 2), and close to 35 percent was observed in some hand specimens at the U-Thor deposit. Some monazite and a few grains of allanite (?) are also present. A more detailed discussion of the mineralogy and petrography of the gneiss is given under "Xenotime Mineralization."

Palms Granite

Miller (1938, p. 421) named the Palms Granite for its typical and extensive development in the Fortynine Palms Canyon area, 3 miles west of Joshua Mountain (figure 1). He noted that "the rock is typically a true granite, varying locally to quartz monzonite" and that the granite facies is largely well foliated whereas the quartz monzonite facies is massive. The average mineral composition for foliated granite, as given on p. 421, is as follows:

Quartz	37 percent
Microcline (commonly perthitic)	43 percent
Orthoclase	4.2 percent
Microperthite	2 percent
Oligoclase	8.3 percent
Biotite	2.3 percent
Magnetite	1.1 percent
Sericite	0.7 percent

With traces of epidote, zircon, allanite, sphene, apatite, and garnet.

Massive quartz monzonite in the lower part of Fortynine Palms Canyon was reported to have the following average mineral composition:

Quartz	28 percent
Microcline	17 percent
Microperthite	11.3 percent
Oliogoclase	36 percent
Biotite	4.3 percent
Epidote	1.3 percent
Magnetite	0.7 percent
Sericite	0.4 percent
Garnet	0.6 percent

With traces of zircon, sphene, allanite and apatite.

Rogers (1954, Map Sheet 24) changed the name Palms Granite to "Palms Quartz Monzonite", and split it into three units which were designated A, B, and C. Unit A is coarse to medium grained, whereas Unit C is fine grained; both are massive. Unit B is foliated, and all three units, apparently, are considered to contain nearly equal amounts of quartz, potash feldspar, and plagioclase (An_{10}–An_{25}), and to be intrusive into the Pinto Gneiss.

The rock was examined in detail only near its contact with the Pinto Gneiss north and east of the Uranus 2 deposit (map 1). Here it is white to gray, contains a faint biotite foliation and is composed essentially of the same minerals in roughly the same proportion as that given by Miller for his foliated granite facies. With this composition the unit, in this area at least, must be considered a granite. It is possible, however, that rock adjacent to the east side of the Music Valley might vary locally to quartz monzonite.

A thin section study shows that virtually all the crystals are anhedral and interlocked in a complex fashion much resembling a texture induced by metamorphism. Albite occurs in both individual crystals and as intergrowths with microcline to form perthite and antiperthite; it is much altered to kaolinite and sericite. Quartz is cracked, strained, granulated and shows undulatory extinction. Prismatic sections seem to be faintly oriented with the biotite foliation.

Gold Park Gabbro-Diorite

Gold Park Gabbro-Diorite is the name given by Miller (1938, p. 419) to a composite igneous rock suite in the Gold Park area that includes diorite, olivine gabbro, gabbro, norite, and hornblendite. He indicated that the average mineral composition is about that of gabbro-diorite. Only hornblende diorite and porphyritic hornblende diorite were observed in the area studied for this report.

Hornblende Diorite

Typically the rock is massive and composed of an intergrowth of black hornblende and plagioclase feldspar in nearly equal amounts. Quartz and biotite are present but only in minor proportions. This intergrowth of dark and light minerals lends a "salt and pepper" appearance to a fresh rock sample; the color index, based on an average of 45 percent mafic min-

erals, places the rock in the mesocratic class of Shand (1947). A few grains of xenotime were observed in the diorite adjacent to its contact with the mineralized Pinto Gneiss at the U-Thor deposit (figure 10). Several small crystals of monazite were observed in thin sections of the diorite, southwest of the Ajax prospect near a road intersection (map 1). The monazite occurs in fine-grained angular crystals which display mild pleochroism (colorless to faint brown). In general, surficial rock is weathered and stained to a dull brown.

Typically the diorite contains nearly equal amounts of medium-grained subhedral laths of calcic andesine intergrown with stubby prisms of green pleochroic hornblende. Feldspar occurs in Albite and Carlsbad twins that locally are normally zoned, and is much altered to sericite. Hornblende is pleochroic from dark green through olive green to pale yellow brown ($z>y>x$), with an extinction angle ($Z\wedge c$) that ranges from $-14°$ to $-20°$; locally it is altered to pale green and weakly pleochroic shreds of chlorite. Some of the hornblende occurs in clusters of interlocking crystals. Both plagioclase feldspar and hornblende enclose abundant irregular, prismatic, and six-sided basal grains of apatite. Most of the apatite, however, is in the hornblende laths. A small proportion (generally 1 to 3 percent) of thin, elongate and occasionally curved laths of yellow-brown biotite are also present. In the diorite-gneiss contact zone at the U-Thor deposit, however, the biotite content is about 15 percent. Quartz in subhedral and cracked grains is usually present, but constitutes only 1 to 3 percent of the rock studied. Prisms of zircon and opaque crystals and blobs of magnetite locally altered to hematite occur in fractions of a percent.

Porphyritic Hornblende Diorite

Because the hornblende laths in this unit are much larger than the feldspar crystals in the matrix, and usually larger than the hornblende in the previously described diorite unit, it is given a separate designation. In addition, there are greater amounts of hornblende in this phase giving the rock a higher color index, about 55 to 65 percent. The mineral composition is essentially the same as for the hornblende diorite. Contacts between the two phases are gradational.

Dikes

Andesitic Bosolt Dikes

The dikes are dark green to black, even though they contain only 50 to 60 percent mafic minerals. The minute grain size lends the rock a deep color. One dike which intrudes hornblende diorite about 12 feet north of the diorite-gneiss contact at the U-Thor deposit was studied in detail. It is roughly lenticular in plan, 4 feet wide and 20 feet long (figure 6).

A thin section study revealed that fractured phenocrysts of olivine, as large as 3 mm., are set in an intergranular matrix composed of randomly oriented microlites of green pleochroic hornblende, interstitial grains of labradorite, and sporadic crystals of augite and olivine. The olivine phenocrysts make up about 3 percent of the dike, and locally are enclosed by thin coronas of hornblende, most likely a result of the incomplete reaction of olivine with the original melt. "Iddingsite" occurs as an alteration product of olivine, particularly in fractured zones. Epidote and chlorite are present in minor amounts as alteration products of the hornblende and olivine. Magnetite is scattered throughout the groundmass, and also occurs as granular aggregates in the olivine phenocrysts.

Aplite Dikes

Aplite bodies are white to gray, generally long and narrow, and are of granitic composition. They were studied in petrographic detail at the U-Thor deposit. Here, the longest dike is 2 to 3 feet wide and exposed for nearly 80 feet along the strike (figure 6).

In thin section this rock displays an anhedral-granular * intergrowth of quartz, albite, microcline, orthoclase, and microperthite, with some epidote, muscovite, biotite (slightly altered to chlorite) and magnetite. Quartz occurs in clear but cracked grains and comprises about 50 percent of each dike. Partially sericitized potash feldspars make up approximately 25 percent of each dike. Locally orthoclase contains subparallel ribbon-like bodies of quartz, especially along cleavage planes. Mildly sericitized and occasionally normally zoned laths of albite are present in amounts varying from 5 to 25 percent. Colorless to pale green prisms of epidote are common, generally in amounts less than 3 percent. One dike, however, contains nearly 50 percent epidote (Ae, figure 6). Thin elongate veins of sericite occur locally cutting all other grains.

Vein Quartz

Massive, fractured, and often oxidized thin veins of milky quartz are common. Locally they contain gold. Pyrite cubes altered to hematite and hydrous iron oxides are common constituents.

Alluvium

Two distinct types of alluvium are readily recognizable. Detritus deposited during the older cycle of erosion is nearly flat lying, fairly well bedded, and contains material ranging in size from boulder to silt. For the most part it seems to be composed of fairly well consolidated and largely unaltered locally derived debris. The true thickness of this unit is not known,

* As here used anhedral-granular is synonymous with allotriomorphic-granular, xenomorphic-granular or aplitic—all meaning that the contained crystals are mostly anhedral.

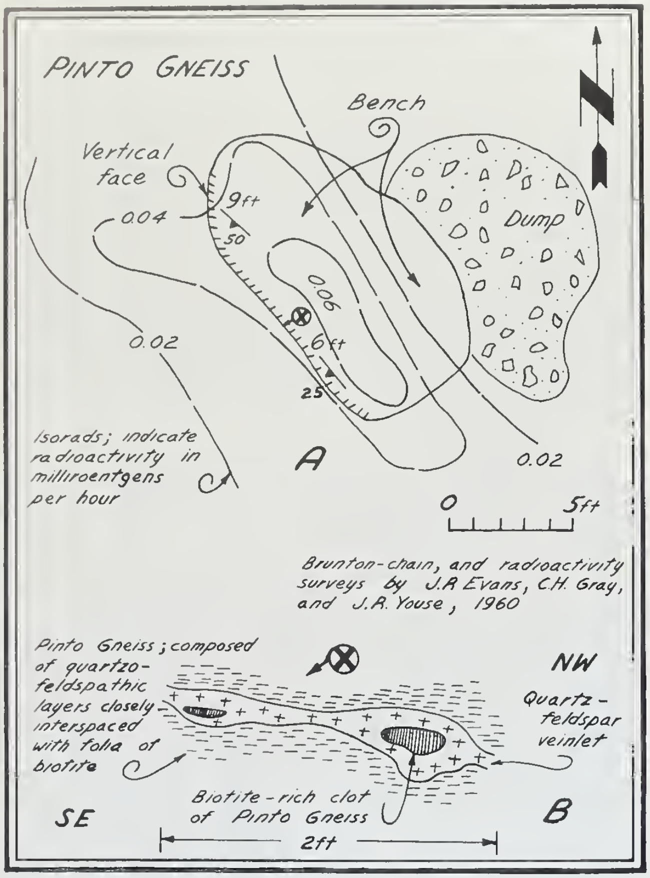


Figure 2. Geologic and isorad map of the Baby Blue (Dixie Girl) prospect.

but it could be very thick, even though local in areal extent (map 1). Younger debris comprises Recent stream laid fill, talus, and rock fall material of all sizes and shapes.

XENOTIME MINERALIZATION

Areal Distribution and Discussion of Mineral Deposits

In a general way, the rare-earth mineral deposits in the southern Music Valley area occur in a northwest-trending belt about 3 miles wide and 6 miles long (figure 1 and map 1). Shallow and relatively barren prospect pits dot the mountains on both sides of the valley.

Xenotime is almost entirely confined to the Pinto Gneiss where it is irregularly distributed and only locally concentrated in sufficient quantity to give an abnormal radioactive anomaly. It nearly always occurs in biotite-rich lenses, pods, and folia.

The varied geologic relationships at each of the deposits point up one or more important features from which part of the summary regarding the origin of mineralization is drawn.

Ajax and Baby Blue (Dixie Girl) Prospects

The Ajax prospect consists of four shallow pits, all in foliated Pinto Gneiss about one-eighth of a mile northeast of its contact with porphyritic hornblende diorite (map 1). The upper two pits are in a northeast-trending, minor fault zone. No mineralization was observed here and no radioactive anomaly was recorded.

At the Baby Blue prospect a shallow vertical cut has exposed mildly radioactive Pinto Gneiss (figure 2 and map 1). Gneiss adjacent to the cut is coated by desert varnish and is generally weathered to a depth of about 1 foot. Locally, rock is stained rusty-brown, especially along fractures; likely the result of the weathering of magnetite and iron-rich biotite.

Folia of biotite, a fraction of an inch to 2 inches thick, trend northwest and dip south from 25° to 50°. The folia are closely interspaced with quartzo-feldspathic zones, and locally are interrupted by coarse-grained augens of oligoclase. Here the gneiss is composed of 30-50 percent biotite with abundant quartz and oligoclase and minor amounts of microcline and orthoclase.

Meager amounts of xenotime and monazite occur in the biotite folia and are readily visible only in thin section. Radioactive anomalies are very mild and the maximum reading recorded was 0.06 mr/hr above background (figure 2).

Peerless Nuclear Minerals Deposits

Claims leased by Peerless Nuclear Minerals, Inc., P. O. Box 243, Rialto, California include the Hansen Number 2, and Uranus numbers 2, 4, and 6. Several claims between the Uranus Group and the Hansen Group, known as the Thunderbird Group, are also leased by the company.

Hansen Number 2 Deposit

A small pit has been dug in well weathered, sheared Pinto Gneiss cut by a narrow andesitic-basalt dike. The rock in the pit is discolored along fracture surfaces in the same manner as at the Baby Blue (Dixie Girl) Prospect. Medium- to coarse-grained augens of oligoclase interrupt the thin biotite folia which contain small amounts of microscopic xenotime and monazite (?) crystals. Foliation trends north and northwest, and dips from 35° east to 60° northeast respectively. Radioactivity is mild to medium in intensity and the maximum anomaly of 0.45 mr/hr was recorded in a shear zone at the northeast end of the pit (figure 3).

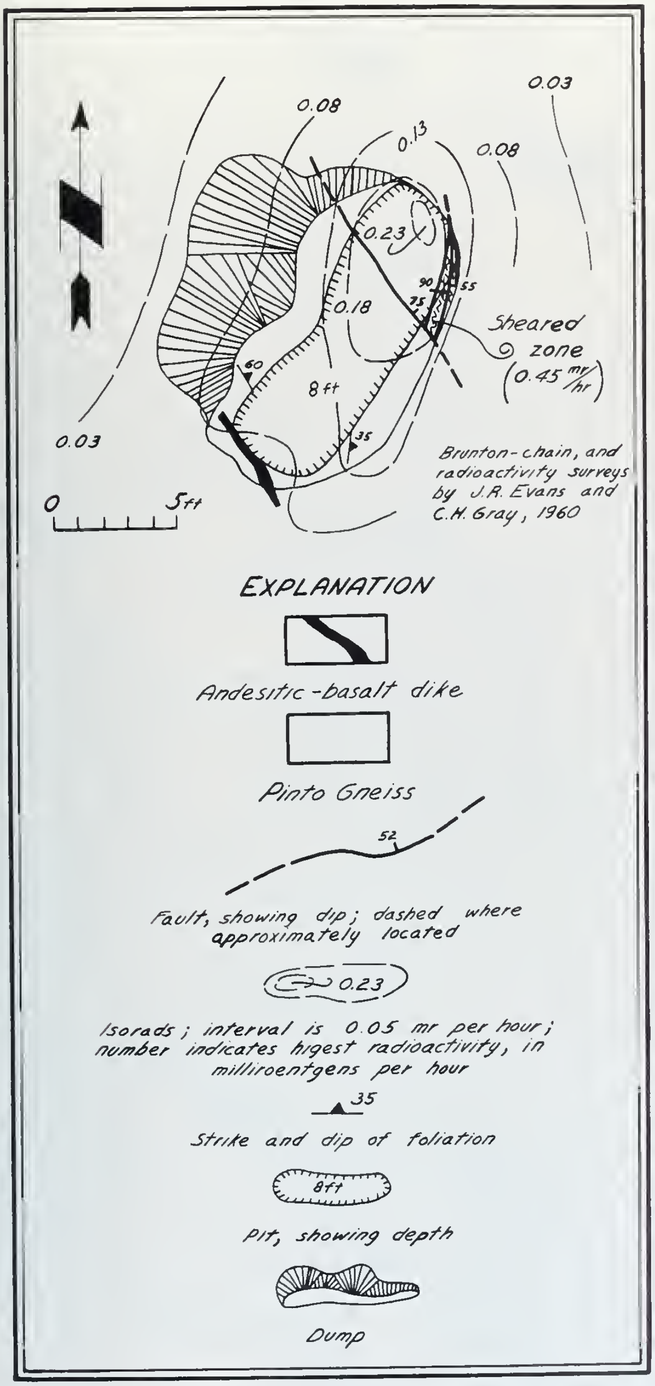


Figure 3. Geologic and isorad map of the Hansen Number 2 deposit.

Uranus Number 2 Deposit

Highly sheared Pinto Gneiss has been exposed by a bulldozer cut and two shallow open cuts. Biotite folia in the gneiss are as much as 2 inches thick, but average only about 1 inch. Rock is weathered to a depth of 1 foot to 2 feet and is stained rusty-brown along fracture planes. The biotite is locally altered surficially to a gold-colored material. Radioactivity is nil except in one small area (figure 4) where an anomaly of 0.38 mr/hr was recorded. Thin sections of gneiss here showed minor amounts of very fine grained xenotime and monazite (?) in biotite rich areas.

Uranus Number 4 Deposit

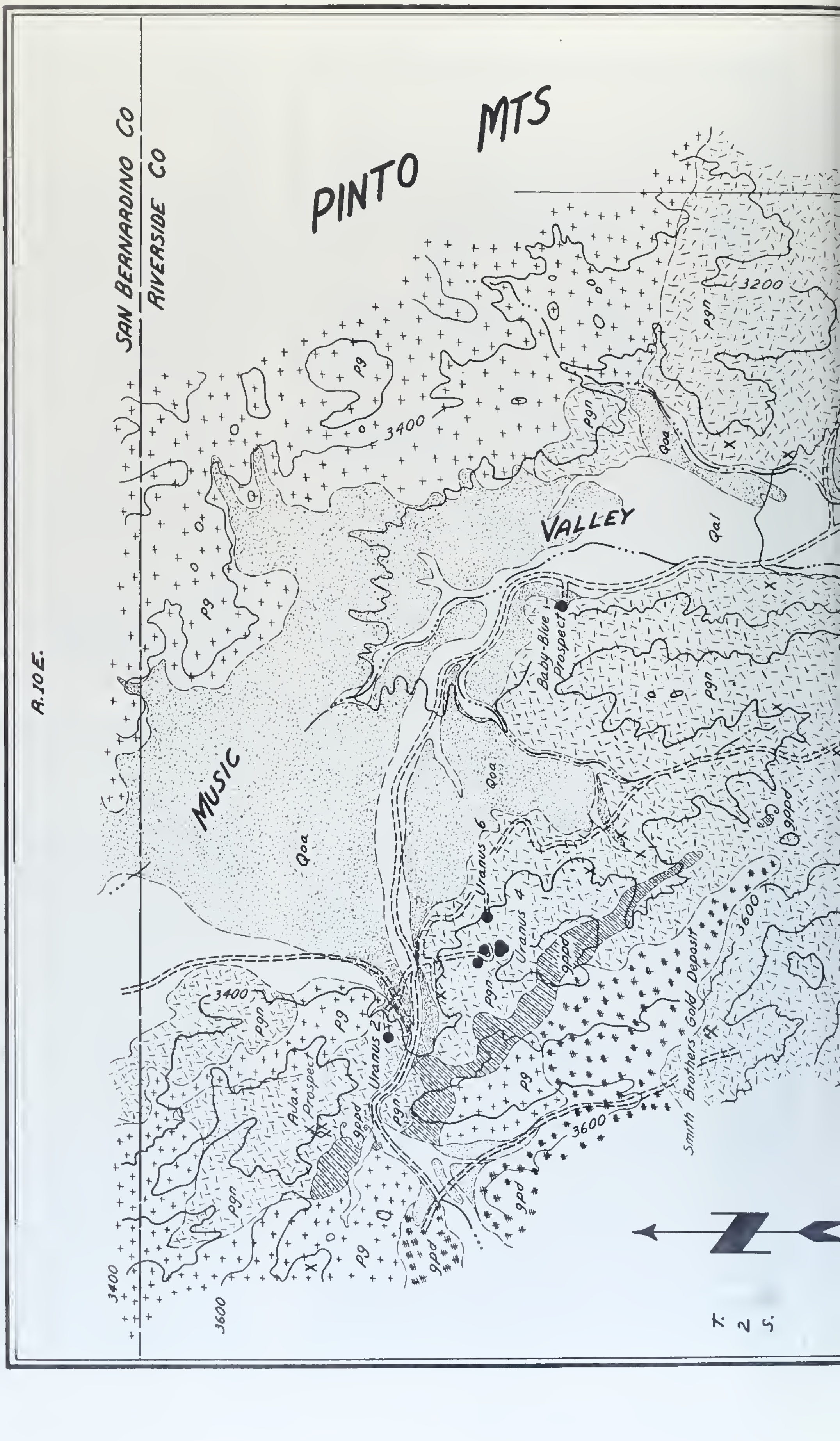
Several areas of anomalous radioactivity have been explored at the Uranus Number 4 deposit (figures 4 and 5). An anomaly of 1.8 mr/hr was reported here by Walker, Lovering, and Stephens in 1956 (p. 26). Probably this reading was recorded at Pit 2 which provided most of the 500 tons of Pinto Gneiss that has been stockpiled at the Silver Bell processing plant located 2½ miles north of Twentynine Palms on Utah Trail. The radioactivity of the stockpile ranges from 0.08-0.24 mr/hr, averaging 0.11 mr/hr. Radioactivity anomalies of mild to medium intensity near Pits 2 and 4 are shown in figure 4. There are two areas that have relatively high readings; one is just south of Pit 4 (0.22 mr/hr), and the other near the face of Pit 2 (0.15 mr/hr). Radioactivity was more intense here before the removal of rock to the stockpile. A pronounced radioactive belt about 300 feet long and close to 60 feet wide extends from the area adjacent to Pits 3 and 6 through Pit 4 and open cut 5, to open cut 1 (figure 5). The central part of this belt has an anomaly of 0.12 mr/hr.

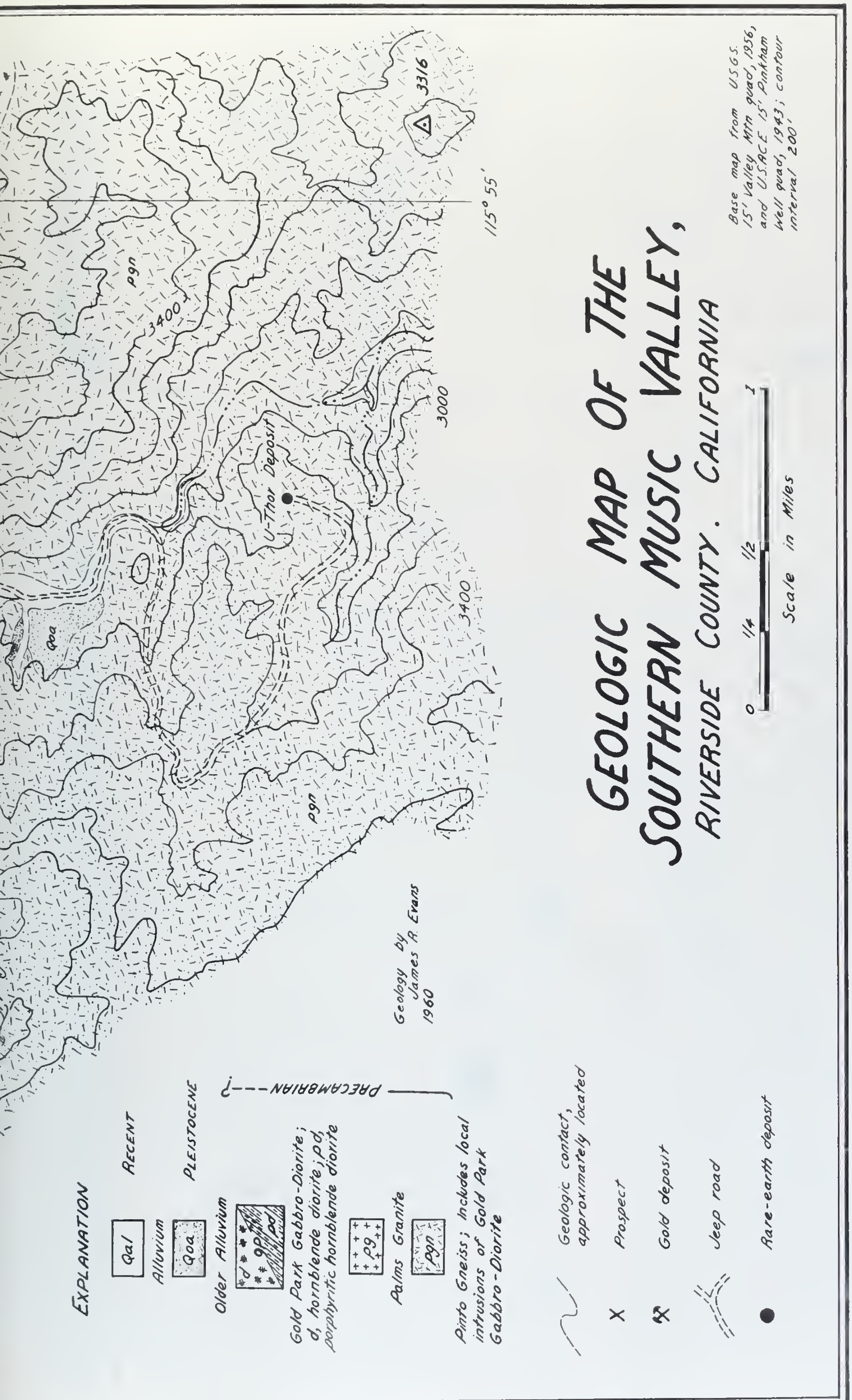
The highly fractured gneiss in the vicinity of Pits 2 and 4 is rich in chlorite. It is cut by a prominent north-trending, steeply west-dipping shear zone (figure 4). A crumbly and well weathered andesitic basalt dike is contained in this sheared zone. Broken, finely sheared hornblende diorite that is intrusive into the gneiss is exposed in the northeast part of Pit 2. A reddish-brown soil, 1 to 3 feet thick, caps the gneiss at the top of the ridge near Pits 3 and 6. The soil zone is well exposed near the top of Pit 3.

In addition to biotite folia, xenotime and monazite (?)-bearing biotite-rich pods nearly one and one-half feet thick and 3 to 5 feet long are interlayered with quartz-sodic oligoclase zones. The pods are exposed in the face of Pit 2 where the radioactivity is most intense.

Uranus Number 6 Deposit

Only one small area was found to be radioactive at this deposit. A moderately intense anomaly of 0.40 mr/hr was recorded at the top of the extreme south end of the elongate 11-foot deep cut (figure 4). The anomaly was recorded in well-weathered Pinto Gneiss which is in fault contact with hornblende diorite. A thin section study showed that irregular grains of altered xenotime and monazite (?) are responsible for


PINTO MTS
MUSIC
VALLEY
SAN BERNARDINO CO
RIVERSIDE CO
R.10E.
Baby-Blue Prospect
Uranus 6
Uranus 4
Uranus 2
Ajax Prospect
Smith Brothers Gold Deposit
3200
3400
3600
Qoa
Qal
pg
pgn
gpd
T.2S.


GEOLOGIC MAP OF THE SOUTHERN MUSIC VALLEY,
RIVERSIDE COUNTY. CALIFORNIA
Base map from U.S.G.S. 15' Valley Mtn quad, 1956, and U.S.A.C.E. 15' Pinkham Well quad, 1943; contour interval 200'
0 1/4 1/2 1
Scale in Miles
Geology by James R. Evans 1960
115° 55'
3316
3400
3000
U-Thor Deposit
Qoa
Pgn
EXPLANATION
Qal Alluvium
RECENT
Qoa Older Alluvium
PLEISTOCENE
Gold Park Gabbro-Diorite; d, hornblende diorite; pd, porphyritic hornblende diorite
Pg Palms Granite
Pgn Pinto Gneiss; includes local intrusions of Gold Park Gabbro-Diorite
PRECAMBRIAN---?
Geologic contact, approximately located
Prospect
Gold deposit
Jeep road
Rare-earth deposit

Map 1.

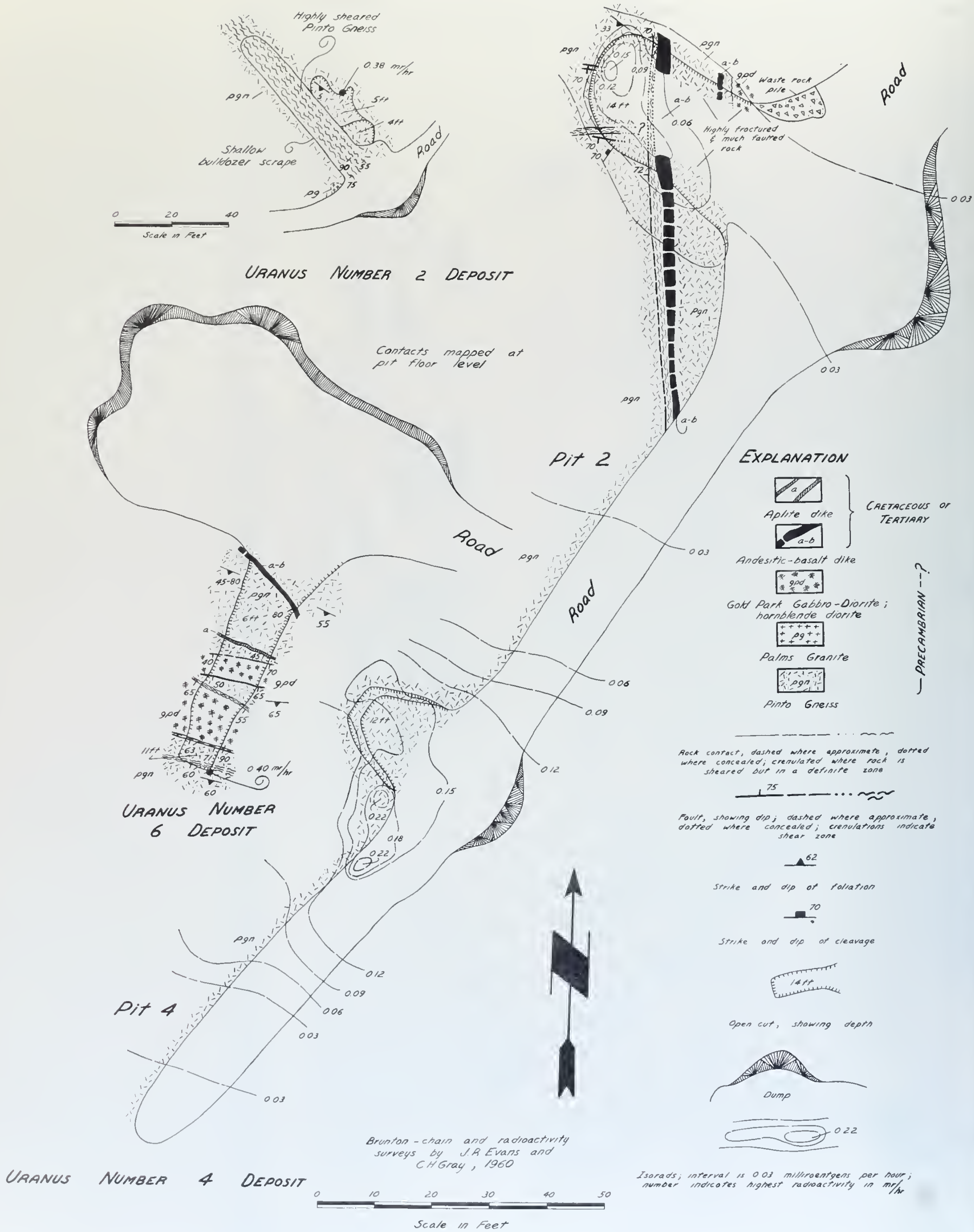
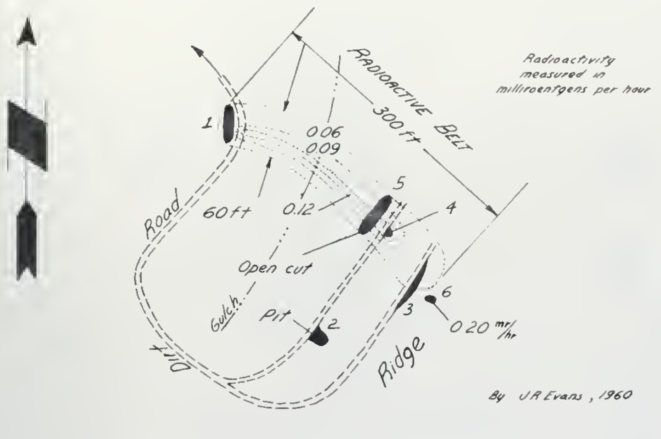


Figure 4. Geologic maps of the Uranus Numbers 2 and 6 deposits, and a geologic and isorad map of the Uranus Number 4 deposit.



URANUS NUMBER 4 DEPOSIT

Figure 5. Sketch of the workings at the Uranus Number 4 deposit showing the trend and extent of the radioactive belt.

almost all the radioactivity. The alteration product is an orange to brown substance, probably hydrous iron oxides. A few minute grains of allanite (?) were also observed.

Foliation in the gneiss trends nearly west and dips south from 45° to 80°. In general the folia range from one-eighth of an inch to one-quarter of an inch in thickness. At the face of the cut, however, there are biotite rich pods as much as a foot and a half thick.

A punky west-trending andesitic basalt dike and an aplite dike both cut the gneiss near the front of the pit. Bedrock in this area is capped by 6 inches to 1 foot of red-brown soil, and is much weathered 2 to 3 feet lower.

U-Thor Deposit

The three U-Thor claims are on top of a northwest-trending hill that rises abruptly about 500 feet above the flat sandy floor of Music Valley to a maximum elevation of 3,214 feet (figure 1 and map 1).

Much of the hilltop is underlain by highly radioactive Pinto Gneiss. An anomaly of 1.7 mr/hr was recorded in a pit near the central part of the area mapped (figures 6 and 7). An anomaly of 0.8 mr/hr was recorded in a less pronounced center of radioactivity 90 feet southeast of the pit adjacent to a steep but low cliff. An elongate radioactive zone about 270 feet by 135 feet surrounds the pit area, and roughly defines the surface shape and areal extent of mineralized gneiss.

Gneiss in the pit area is extremely biotite-rich and contains abundant orange grains of xenotime readily visible to the unaided eye (photo 3). Xenotime composes nearly 35 percent of selected hand specimens. Minor quantities of monazite and allanite (?) are also present.

Hornblende diorite intrudes the gneiss, and is poorly exposed as two tabular bands nearly isolating a small central body of gneiss from two larger outlying bodies. Diorite is also exposed in the bottom of the pit (figures 6 and 7). Foliation in the gneiss trends generally southwest and dips from 25° to 38° south. It is fairly constant in both direction and magnitude in each body of gneiss. The diorite-gneiss contact is gradational across 2 to 5 feet. In the contact zone the diorite contains as much as 15 percent biotite, whereas the usual content wherever else studied is only 1 to 3 percent biotite. Narrow aplite dikes and small irregular bodies of quartz cut both the hornblende diorite and the gneiss. A small lenticular dike of andesitic basalt cuts the diorite near its contact with the gneiss in the southeastern part of the area mapped.

Exploratory work consists of several shallow prospect pits and open cuts. The largest pit, in the center of the area mapped, is 37 feet long in an east-west direction, 7 to 15 feet wide, and 1 to 7 feet deep. Nearly 3 miles of often steep but good dirt road lead to the area from the sandy Music Valley road. About 50 tons of mineralized gneiss have been removed from the pit, transported to the mill 3½ miles southeast of Twentynine Palms, and stockpiled (figure 1).

Radioactivity

As has been demonstrated in the previous section, strong anomalies are obtained wherever xenotime and monazite are concentrated in the Pinto Gneiss. Radioactivity is a result of the decay of thorium into its daughter products, and is a rough measure of the thorium and rare-earth content of the gneiss (figure 11). As these two materials increase in quantity the radioactivity increases in intensity. The relation is not a precise straight line function and the line on figure 11 illustrates only a strong general trend. Even with this limitation the radioactive anomalies give a general idea of the amount of rare-earths present, and are a most useful guide for prospecting and for a rough evaluation of known deposits. A further explanation of the chart is presented in the section on computing ore reserves.

The average background in the area along the west side of Music Valley from Gold Park south to the U-Thor deposit is about 0.03 to 0.05 mr/hr, and the isorads in the various figures all reflect radioactive anomalies above background.

Petrographic Mineralogy of Mineralized Pinto Gneiss

Xenotime is consistently associated with radioactive biotite-rich areas in the Pinto Gneiss. It does

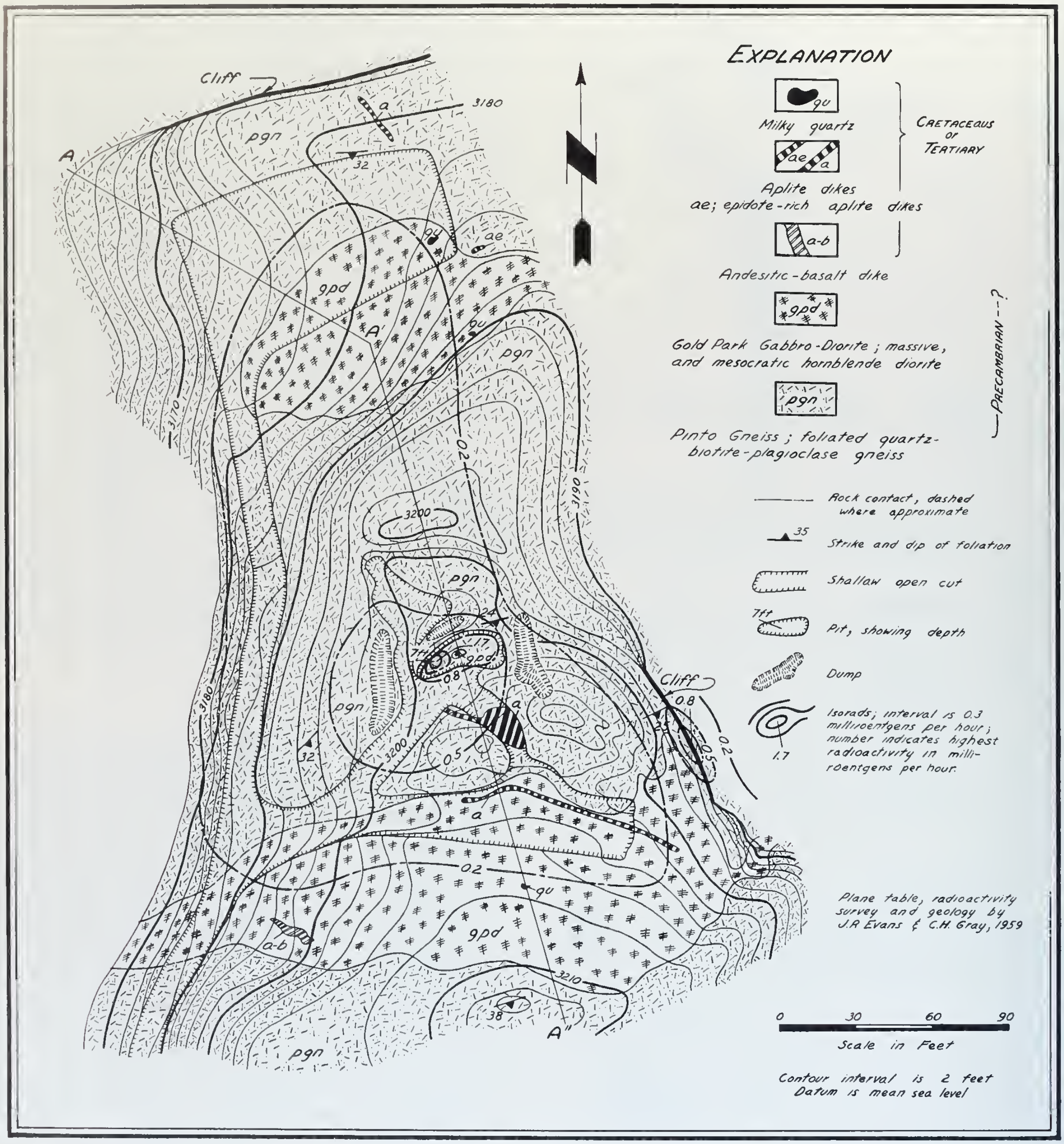


Figure 6. Geologic and isorad map of the U-Thor deposit.

occur in quartzo-feldspathic parts of the gneiss but never in significant concentrations. In the biotite areas, fine to coarse grained crystals of xenotime are intergrown with brown pleochroic biotite, plagioclase feldspar, and quartz, with meager quantities of magnetite (locally altered to hematite), apatite, zircon, sphene, and allanite (?) (figures 8 and 9). Minor amounts of monazite, actinolite, orthoclase, microcline, perthite, and muscovite are present locally.

Biotite occurs in long, narrow and occasionally curved laths which nearly always have a pronounced orientation. At the Baby Blue prospect and the Uranus 4 and 6 deposits the biotite contains minute radioactive grains surrounded by dark halos. A few grains are brown and faintly pleochroic, possibly allanite (?). Other clear grains are very likely zircon (figure 8). Locally biotite is much altered to chlorite, especially in the vicinity of the Uranus 4 deposit.

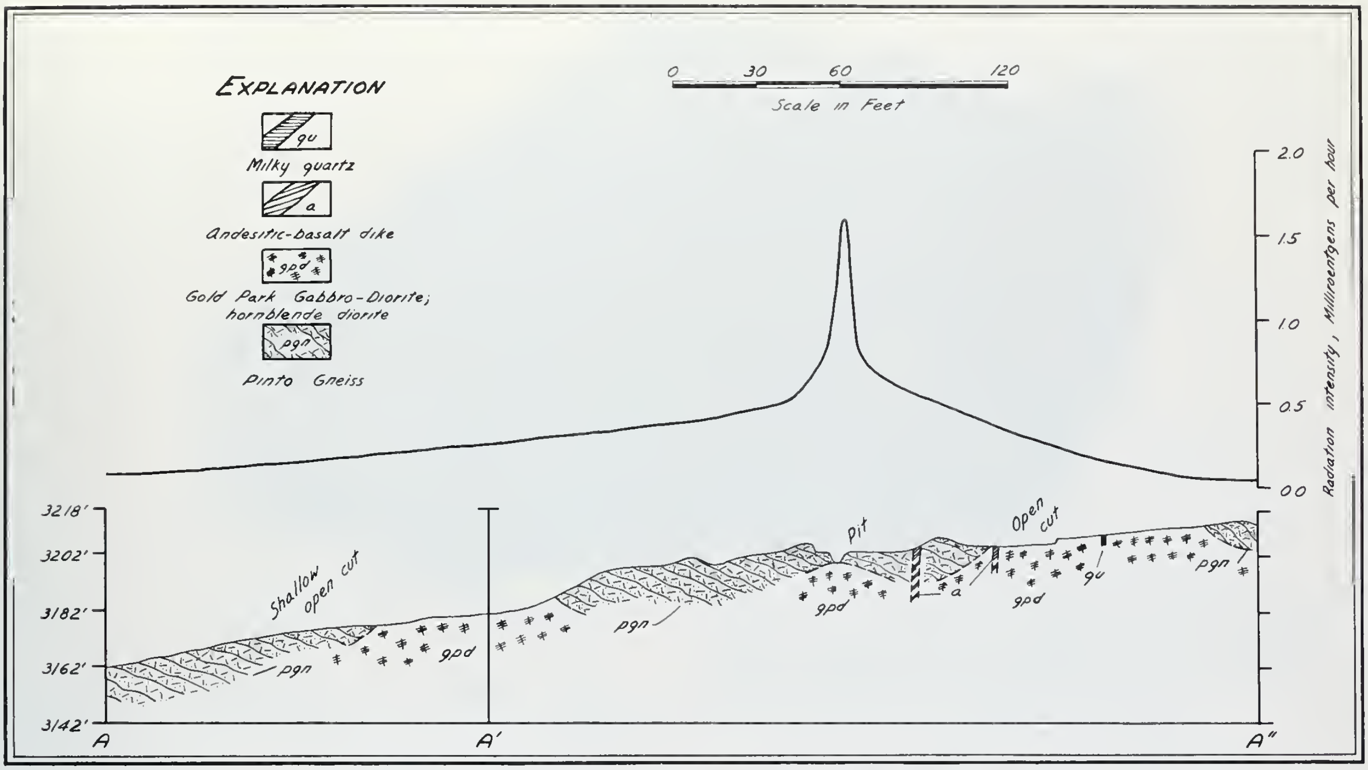


Figure 7. Structure section A, A', A' ', and radiation intensity profile, U-Thor deposit.

Figure 8 (belaw). Mildly radioactive Pinto Gneiss from the Baby Blue prospect showing biotite falia containing subhedral basal and prismatic groins af xenotime. The basal sectian of biotite in the center of the drowing contains radiooctive allanite(?) and zircan grains surraunded by dark halos created by radiaactive emanatians.

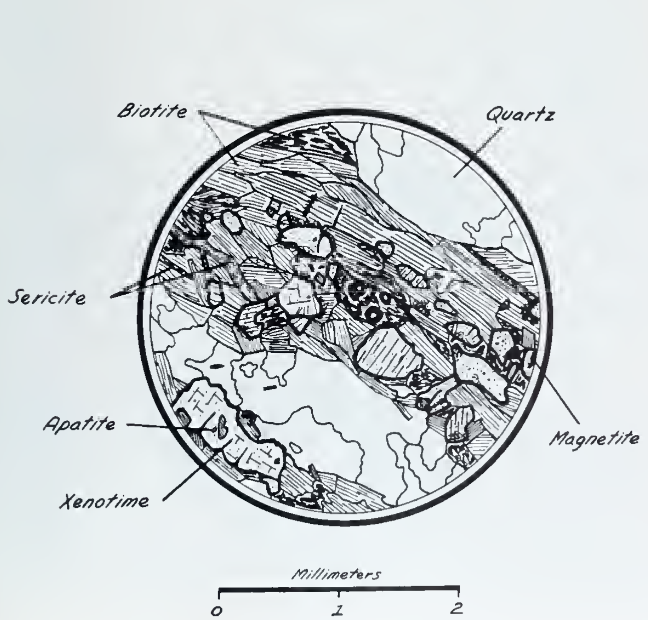


Figure 9 (below). Highly rodioactive Pinta Gneiss from the pit at the U-Thor deposit displaying slightly altered xenotime crystals set in a motrix composed daminantly of brown pleochraic biotite laths.

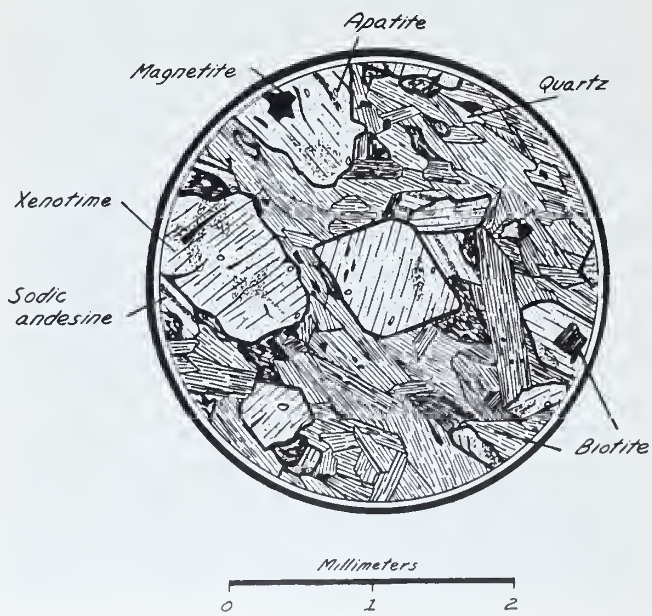


Photo 3. Cut section of Pinto Gneiss showing grains of xenotime in a matrix of dark magnetite, and short prismatic crystals of pale green actinolite. The specimen is from the pit at the U-Thor deposit. Map 1. (No further caption).

Quartz ranges in size from minute anhedral grains to roughly rectangular shaped crystals nearly 10 mm long and 4 to 6 mm wide. These large crystals are elongate parallel to the crystallographic axis and are closely oriented with the biotite folia. Most of the quartz displays highly irregular crystal boundaries and is commonly crushed and cracked, displaying undulatory extinction. Crystals generally are clear but locally they contain abundant minute inclusions.

Plagioclase feldspar varies in modal composition from about An_{10} to nearly An_{38}. The most calcic feldspar (sodic andesine) was observed in thin section from the biotite-rich areas near the gneiss-diorite contact in the pit at the U-Thor deposit. Otherwise, all the feldspars studied at all the deposits consist of fine- to coarse-grained subhedral laths of kaolinized and sericitized oligoclase.

Actinolite was observed in pale green and faintly pleochroic crystals in the biotite-rich area in the pit at the U-Thor deposit. Clusters of short prismatic crystals surround megascopic grains of magnetite and xenotime. The extinction angle of actinolite varies from $-15°$ to $-18°$, an indication of low to medium iron content (photo 3).

Monazite is present in some of the material examined. At times it is most difficult to distinguish optically from xenotime. D. F. Hewett, U. S. Geological Survey at Menlo Park, has pointed out that although most monazite is biaxial (monoclinic crystal system) in thin section, some specimens high in thorium are very nearly uniaxial (oral and written communication, 1961). Monazite collected by Hewett from the Black Dog claim near Rock Corral, San Bernardino County, contained 15-16 percent thorium oxide and 0.4 percent uranium, and is almost uniaxial. Further preliminary studies with Howard Jaffe in Washington, D. C., showed that as the thorium oxide content in monazite rises, the axial angle declines until at about 16 percent the mineral is virtually uniaxial.

Basal sections of monazite from the U-Thor deposit displayed a definite breaking isogyre and a 2V that ranged from about 5 to 10 degrees. Grains are largely metamict and show higher relief than do the xenotime crystals. Most of the samples examined appeared to contain much more xenotime than monazite. The possibility exists, however, that some high thorium monazite has been misidentified as xenotime. Results of the spectrographic analyses (Table 2) show a marked excess of yttrium to cerium. Based on the material studied, most of the radioactive material is thought to be xenotime.

Mineralogy of Xenotime

In thin section xenotime is seen in colorless to light brown short tetragonal crystals, locally showing a combination of first order prism and dipyramid (figure 9). The mineral occurs in a wide range of sizes and grains which occasionally exhibit ragged anhedral crystal boundaries. The largest crystal observed, 8 mm by 5 mm, was at the U-Thor deposit. Prismatic cleav-

age {110} was observed and many grains show a well developed but generally uneven fracture (figures 8 and 10). Some grains show a well developed parting (?) parallel to {001}. Locally the mineral is metamict and cleavage traces have been disrupted by radioactive disintegration. Hardness is roughly 4½ but much of the mineral, especially where it occurs near the ground surface, has been altered to a soft, orange, opaque substance, probably hydrous iron oxides (Molloy, 1959, pp. 520-523). The mineral has a specific gravity of about 4.5; it is paramagnetic.

The optical properties are summarized below.

n_E	1.82	Tetragonal; ditetragonal-dipyramidal
		Uniaxial; (+)
n_o	1.72	Relief: high
		Colorless; but locally altered to an orange opaque substance
$n_E - n_o =$	0.10	Birefringence: very strong
		Extinction: parallel to cleavage traces

Origin of Mineralization

Before coming to any conclusion regarding the mode of origin of the xenotime, it seems best first to tabulate some pertinent data, part of which has been presented in the preceding sections.

1) In general, the mineral deposits in the southern Music Valley occur in a northwest-trending belt about 3 miles wide and 6 miles long.
2) Mineralization is not confined to fault zones or to highly faulted areas; it is spatially unrelated to dikes of any composition. For example, a major northwest-trending and steeply dipping shear zone 10-14 feet wide at the Uranus Number 2 deposit is not mineralized, but an anomaly of 0.45 mr/hr was recorded at the Hansen Number 2 deposit at the intersection of a northwest-trending and 75° NE dipping fault and a vertical north-trending shear zone. In addition, the largest concentrations of radioactive materials occur at the U-Thor deposit where no faults were detected.
3) Xenotime and monazite are irregularly distributed in the Pinto Gneiss, but nearly always is confined to biotite-rich lenses, pods, and folia. Some areas are barren whereas others contain as much as 35 percent xenotime.
4) The biotite areas are mostly planar, and may represent former bedding planes, but yet only certain local areas are mineralized. In addition, xenotime crystals appear to be either post folia or at least to have grown at the expense of biotite (figures 8 and 9).
5) Xenotime crystals are ragged anhedral to euhedral, and occur in a wide range of sizes. The largest crystals are found at the U-Thor deposit.
6) The mineral constituents of the Pinto Gneiss are indicative of low grade metamorphism.
7) Carron, et al. (1958, pp. 255-256, and 272-273), have synthesized both monazite and xenotime hydrothermally by crystallization from an aqueous solution in a closed system (table 1). Note that xenotime was synthesized at much lower temperatures than monazite. Further experiments showed that at 300° C. and about 90 atmospheres of pressure yttrium phosphate precipitates preferentially to all the cerium subgroup lanthanides. This means

Table 1

Hydrothermal syntheses of hexagonal $CePO_4$, monoclinic monazite ($CePO_4$), tetragonal xenotime (YPO_4) and tetragonal churchite (from Carron, Naeser, Rose, and Hildebrand 1958, p. 255). The $CePO_4$ is isostructural with rhabdophane, a hydrated, cerium group rare-earth phosphate (Palache, Berman, Frondel, 1951, p. 774). The composition of churchite (weinschenkite) is $YPO_4.2H_2O$. It is isostructural with xenotime.

Experiment	Constituents[1]	Temperature (degrees centigrade)	Duration (days)	Predominant phase identified
1	$CeCl_3$, HCl, H_3PO_4	100±3	5	Hexagonal $CePO_4$.
2	do	150±3	5	Do.
3	do	200±3	5	Do.
4	do	250±10	5	Do.
5	do	300±10	5	Monazite.
6	YCl_3, HCl, H_3PO_4	300±10	7	Xenotime.
7	do	250±10	3.5	Do.
8	do	200±3	4	Do.
9	do	150±3	4	Do.
10	do	105±3	4	Do.
11	do	50±3	7	No precipitation.
(2)	do	85±3	6	Do.
(3)	do	95±3	7	Churchite.

[1] 0.1 g of oxide converted to chloride by evaporation to dryness with concentrated hydrochloric acid. The salts were dissolved in 2 ml of water containing 0.15 ml of concentrated hydrochloric acid. One ml of 2.1 percent (by volume) phosphoric acid was added with sufficient water to make a 4-ml volume.
[2] Solution, experiment 11, resealed and rerun.
[3] Solution, experiment 11, again resealed and rerun.

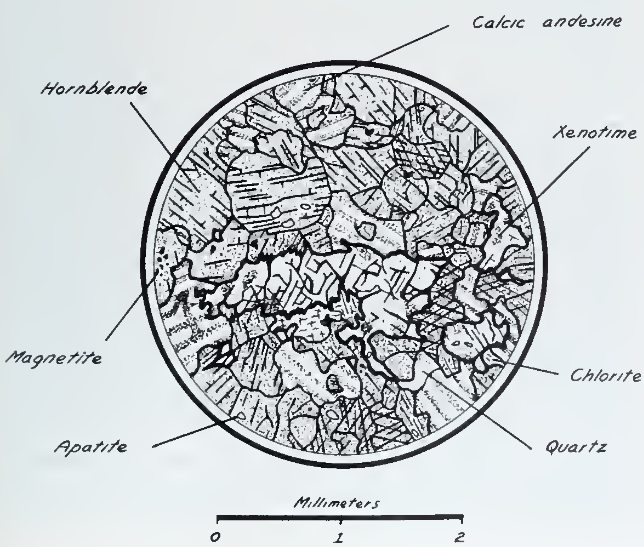


Figure 10 (opposite). Hornblende diorite from a roadcut about 80 feet south of the pit at the U-Thor deposit. Ragged and cracked grains of xenotime ore set in a matrix composed mostly of calcic andesine (locally normally zoned) and stubby pleochroic hornblende laths. Two adjacent crystals of chlorite are in contact with the large xenotime grain in the center of the sketch.

that, experimentally at least, initial precipitates from solutions containing yttrium and all other rare-earth elements should be rich in yttrium. If fractionation occurs under conditions of moderate temperatures and pressures, experimentally, xenotime will fractionally crystallize first. Therefore yttrium and its sub-group lanthanides (Dy, Ho, Er, Tm, Yb, Lu) should combine first with any available phosphorus, coprecipitating minor amounts of cerium subgroup lanthanides. With additional available phosphorus, monazite and its subgroup lanthanides (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb) would form. All this assumes no deposition of monazite prior to the first deposition of xenotime.

8) Overstreet (1960, B55-B57) has indicated that "detrital monazite in pelitic sediments dissociates early in regional metamorphism. Metamorphic monazite then forms in rocks of all but the lowest metamorphic grades and becomes more abundant as the grade of metamorphism rises".

9) Xenotime was detected in the hornblende diorite adjacent to its contact with the Pinto Gneiss. Crystals found in this area are anhedral, much fractured, and are replacing all other mineral constituents (figure 10). No deuteric alteration of adjacent hornblende or plagioclase was observed and it seems unlikely there could have been a deuteric stage of mineralization with a dioritic magma the mineralizing agent. Some plagioclase in the diorite, however, is normally zoned. In addition, the gneiss is mineralized in other areas where there is no adjacent diorite exposed.

10) Several small crystals of monazite were observed in hornblende diorite southwest of the Ajax prospect.

11) Young and Sims (1961) have described xenotime and monazite concentrations at three localities, all in Precambrian biotite gneiss and migmatite, near Central City, Gilpin County, Colorado.

Xenotime and monazite are concentrated in amounts of 1 to 5 percent by volume in zones that are a maximum of 5 feet thick and a few hundred feet long.

The following section is taken from the abstract of their paper:

> "The rare-earth minerals occur dominantly as aggregates of sand-size crystals in thin layers and clots of biotite, which are much coarser than the mica in the typical biotite gneiss. Xenotime is more abundant than monazite in two of the three occurrences. Both minerals are subrounded to rounded and crystal faces are rare. The two minerals appear to have crystallized contemporaneously. Except for magnetite, other accessory minerals that are common to the country rock are not concentrated with the xenotime and monazite.
>
> "The field and laboratory data are consistent with the hypothesis that the rare-earth minerals were concentrated at their present sites during migmatization of the biotite gneiss country rock, in a period of Precambrian plastic deformation. Presumably, granitic fluids derived during the deformation selectively mobilized rare-earth cations and phosphate from the biotite gneiss country rock. These ions crystallized with biotite and locally with magnetite to form zones of xenotime and monazite concentrations in migmatized parts of the gneiss."

Even though the concentration at three widely separated localities are at approximately the same stratigraphic position within a single layer of biotite gneiss, Young and Sims reject a placer hypothesis for the origin of the concentrations. They raise two objections to the placer hypothesis. One objection is that the mineral suite is much simpler than in most known unconsolidated placer deposits. Their second objection is that a mechanical concentration of heavy accessory minerals similar to those contained in the enclosing rocks would yield a concentrate richer in zircon than xenotime. The biotite gneisses at Jasper Cuts and at Fourmile Gulch are reported to contain more zircon than xenotime.

After careful consideration of the above material it seems reasonable to expect that mineral concentrations formed early, either before or during metamorphism. If the gneiss is a metasedimentary rock, the rare-earth minerals could well have been detrital grains in the original sediment, perhaps concentrated locally along bedding planes. These planes might represent zones of relative weakness in which growth of xenotime could readily be accomplished during metamorphism. No particular emphasis is placed upon the fact that an unconsolidated placer deposit might contain a more complex or even different heavy mineral suite.

At certain lower depths in the earth's crust igneous and metamorphic activity and processes no doubt merge. Partial fusion of a metamorphic rock could result in mobilization and migration of contained granitic material. It does seem plausible that a metamorphosed rock containing a placer deposit could be later modified through plastic deformation. Mobilized granitic fluids could inject adjacent parts of the rock in which they were created. This process could alter any existing placer deposit, which probably has already been somewhat altered by metamorphism. The Pinto Gneiss, however, does not appear to have been migmatized, but rather to be the result of metamorphism of a sedimentary and/or volcanic rock sequence.

Meager data indicate that mineralization was the result of either *lit-par-lit* injection of a granitic magma into a pre-existing igneous or sedimentary rock, or intrusion of the hornblende diorite. It seems most reasonable to expect that the diorite at the U-Thor deposit assimilated parts of the gneiss and in the process incorporated an occasional grain of xenotime. The contact between the two rocks here is gradational across 2 to 5 feet, and diorite near the contact contains an abnormal amount of biotite, as much as 15 percent locally. As the diorite should have been emplaced at temperatures that exceeded 700° C., one might expect assimilated xenotime (if cerium earths were available) to be recrystallized as monazite at such temperature. For whatever reasons, the fact is that xenotime was not recrystallized.

Table 2

Semiquantitative spectrographic analyses of Pinto Gneiss, southern Music Valley area

Element	U–Thor 1A	U–Thor 1B	U–Thor 2	U–Thor 3	U–Thor 4	Uranus 2	Uranus 4	Uranus 6	Hansen 2	Hansen 2 Special
Silicon	14.0%	19.0%	17.0%	17.0%	22.0%	9.0%	22.0%	21.0%	31.0%	24.0%
Magnesium	1.4	1.1	1.5	1.3	2.0	0.62	0.46	0.88	1.2	1.5
Calcium	0.17	0.26	0.23	0.30	0.39	0.078	0.37	0.28	0.11	0.18
Aluminum	5.1	6.0	5.9	8.0	6.1	3.2	6.0	3.6	1.8	4.9
Iron	9.6	5.0	9.3	8.6	9.1	3.7	8.0	2.0	4.4	5.0
Titanium	1.6	0.84	1.2	1.5	0.96	1.9	0.59	1.1	0.98	1.6
Manganese	0.083	0.061	0.10	0.096	0.12	0.095	0.028	0.061	0.18	0.12
Barium	0.11	0.097	0.12	0.14	0.15					
Lead	0.040	0.048	0.039	0.033	0.026	0.060		0.075		0.016
Molybdenum	trace	nil	trace	trace	trace				trace	0.012
Vanadium	0.013	0.0081	0.013	0.014	0.014	0.0087	0.010	0.0038	0.032	0.026
Phosphorus	1.5	1.7	1.5	0.73	0.47	4.1		0.93		
Copper	0.00080	0.00052	0.00085	0.0012	0.0024	0.00038	0.00026	0.0033	0.00056	0.00048
Sodium	0.26	0.32	0.31	0.52	0.61	0.22	0.72	0.16	0.075	0.38
Nickel	0.0035	0.0025	0.0039	0.0035	0.0044	trace	trace	trace	0.0056	0.0040
Chromium	0.0049	0.0022	0.0050	0.0062	0.0085	0.0029	0.00064		0.012	0.010
Thorium	0.44	0.47	0.49	0.39	0.31	0.20	*	1.2	0.10	0.20
Cerium	0.64	0.94	0.83	0.59	0.47	0.44	0.14	1.4	0.16	0.28
Ytterbium	0.66	0.56	0.75	0.55	0.46	0.80	trace	0.0064	0.29	0.41
Neodymium	0.30	0.28	0.41	0.24	0.30					
Yttrium	8.8	8.3	7.7	6.4	3.5	7.3	0.032	0.20	3.9	5.4
Lanthanum	0.27	0.33	0.34	0.26	0.27	0.16	trace	0.89	0.067	0.13
Dysprosium	0.38	0.38	0.41	0.32	0.22					
Tungsten	nil	nil	nil	nil	nil					
Lithium	nil	nil	nil	nil	nil					
Uranium	**	**	**	**	**	**	**	**	**	**
Other rare earths						trace	nil	trace	trace	trace
Tin								0.011		

*—not detected; less than 0.10
**—not detected; less than 0.20

Analyses by Pacific Specto-Chemical Laboratory, Los Angeles, California, September 1957 (Uranus and Hansen), April 1958 (U-Thor).

The majority of evidence and the best evidence point to a detrital origin for the rare earth minerals, modified later by metamorphism.

Analytic Data

Spectrographic Analyses

Semiquantitative spectrographic analyses of five grab samples of Pinto Gneiss from the U-Thor deposit were prepared in April 1958 by the Pacific Spectrochemical Laboratory, Los Angeles. Analyses for the Hansen deposit and the Uranus deposits were prepared in September 1957 by the same laboratory (table 2). All these samples were taken by C. A. Richards (oral communication, August 1959).

Sample Numbers 1A and 1B: taken from the pit in an area that gave a radioactive anomaly of 1.4 mr/hr; 1A at a depth of 8 feet, and 1B at a depth of 5½ feet (figure 6).

Sample Number 2: taken at a cliff face 95 feet southeast of the pit.

Sample Number 3: taken from a ledge 3 feet below the road about 100 feet northwest of the pit.

Sample Number 4: taken at a depth of 1½ feet, 300 feet west of the pit, and out of the area mapped.

Hansen Number 2: consisted of rock chips taken every 6 inches for 6 feet across the east face of the pit. Loose material taken from a shear zone over a distance of 4 feet at the north part of the pit comprised the *Hansen Number 2 Special* sample.

Uranus Number 2: consisted of rock chips taken every 6 inches over 15 feet across the back of the upper 5-foot cut adjacent to the site of maximum radioactivity (0.38 mr/hr).

Uranus Number 4: a chip sample was taken every 6 inches over 7 feet across the west side of open cut 1 (figure 5).

Uranus Number 6: was composed of rock chips taken every 6 inches over 11 feet at the southwest end, and high across the rear of the pit adjacent to the radioactive zone (figure 4).

To point up the relation between ground radioactivity, thorium, and phosphorus to total elemental rare-earth content, the pertinent data from table 2 were plotted on a scatter diagram (figure 11). The rare-earth, phosphorus, and thorium content of the samples all show a general increase with an increase in ground radioactivity.

Yttrium content of all the samples except the Uranus 4 and 6 is notably high, and ranges from 3.5 percent to a remarkable 8.8 percent.

Rare-Earth Concentrate Analysis

Two chemical analyses of a grab sample collected in the pit at the U-Thor deposit where the highest

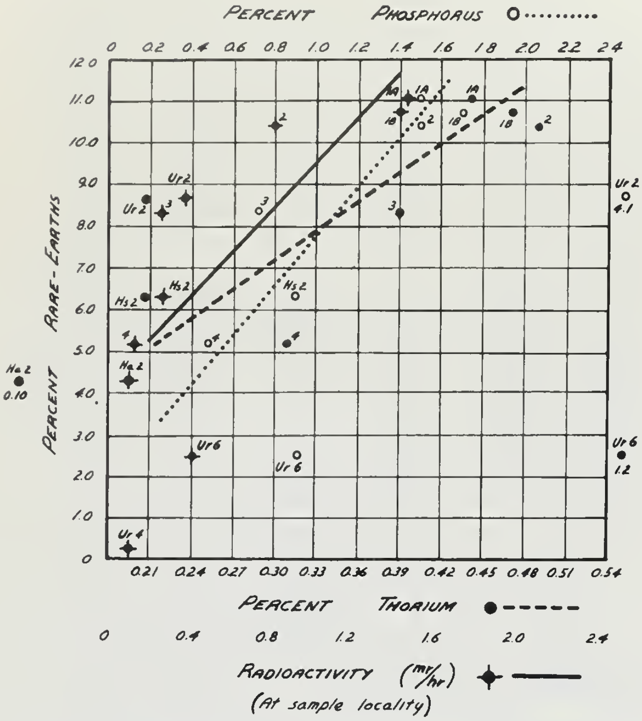


Figure 11. Diagram showing the relation of radioactivity, thorium, and phosphorus to elemental rare-earth content in samples from the U-Thor, Uranus, and Hansen deposits (see table 2). The three lines point up a strong general trend, and can be used for only the most general computations relating rare-earth content to thorium, phosphorus, or radioactivity as a straight line function.

radioactive anomaly was recorded (1.7 mr/hr), were made in July 1959 by the Lindsay Division of American Potash and Chemical Corporation. Part a of Sample 1 is typical xenotime rich Pinto Gneiss. Part b is a relatively pure rare-earth mineral concentrate prepared from Part a by mechanical means (table 3).

Part a contained:
- 8.3 percent cerium and its sub-group lanthanides
- 13.0 percent yttrium and its sub-group lanthanides
- 9.2 percent phosphorus pentoxide
- 0.5 percent thorium oxide

Part b contained:
- 36.2 percent cerium and its sub-group lanthanides
- 19.6 percent yttrium and its sub-group lanthanides
- 25.1 percent phosphorus pentoxide
- 7.3 percent thorium oxide

The relatively high content of cerium and its sub-group lanthanides in Part b is not readily explainable. Perhaps this particular sample was abnormally rich in monazite.

Total amount of Re_2O_3:

Part a: 21.3 percent
Part b: 55.8 percent

A METHOD FOR PROCESSING RADIOACTIVE MATERIAL

Pilot tests show that mineralized Pinto Gneiss can be processed by mechanical means to obtain a xenotime-rich concentrate. After primary jaw crushing, secondary grinding in a ball mill, and screening (— 60 mesh, ASTM), material can be concentrated on Wilfley tables. Table concentrates consist of monazite (G. = 5.5), magnetite (G. = 5.2), zircon (G = 4.7), xenotime (G. = 4.5), sphene (G. = 3.5), apatite (G. = 3.2) and some biotite (G. = 3.0). The biotite has a tendency to adhere to the xenotime crystals and is difficult to remove. Possibly crushing to a finer size may prove more effective in removing the biotite. An effective magnetic separation of the dried Wilfley table concentrates can be made because of the differing magnetism of the components: magnetite is strongly magnetic, xenotime and monazite moderately so, and zircon, sphene, and apatite are practically non-magnetic.

A pilot run in August 1958 on a — 60 mesh (ASTM) material was fairly successful. One of the gravity and magnetic concentrate fractions was analyzed spectrographically and contained 16 percent phosphorus, 0.4 percent titanium, 4.4 percent thorium, 6.5 percent cerium sub-group lanthanides, 18.0 percent

Table 3

Two chemical analyses of material collected from the pit at the site of maximum radioactivity (1.7 mr/hr), U-Thor deposit. Part (a) is from typical but xenotime-rich Pinto Gneiss. Part (b) is a rare-earth mineral concentrate prepared by mechanical means from part (a).

Oxides (in weight percent)	Sample 1	
	a	b
Ce_2O_3	2.5	14.5
Pr_2O_3	0.3	2.2
Nd_2O_3	1.4	8.2
Sm_2O_3	0.3	2.0
Dy_2O_3	0.7	2.2
Ho_2O_3	0.1	0.1
Er_2O_3	0.6	1.0
Yb_2O_3	0.3	0.5
Y_2O_3	6.4	12.7
ThO_2	0.5	7.3
La_2O_3 and others	3.8	9.3
Al_2O_3	10.2	0.1
Fe_2O_3	11.8	1.2
TiO_2	0.2	0.1
Other R_2O_3	4.9	3.1
CaO	2.8	2.3
MgO	5.2	0.5
SiO_2	29.8	4.6
P_2O_5	9.2	25.1
	91.0	97.0
Sp. gr.	3.0±	4.99
Re_2O_3	21.3	55.8

Analyses by Ray Harris, Lindsay Division of American Potash and Chemical Corporation, Chicago, Illinois, July 1959.

yttrium, 2.2 percent ytterbium, and 0.1 percent erbium (C. A. Richards, oral communication, August 1959).

COMPUTING RADIOACTIVE MINERAL RESERVES

A method based principally on the ratio of rare-earth content to radioactivity can be used for roughly estimating a part of the radioactive mineral reserves. An average anomaly reading between two isorads can be computed by adding their respective values and dividing by two. This new value is used to obtain an average rare-earth content from the solid line relation on figure 11 for the Pinto Gneiss between the two isorads, and projected, say, to a depth of 1 foot. The number of cubic feet of gneiss between the isorads and to 1 foot of depth can be closely computed by use of a planimeter. A specific gravity of 3.0 was found to be a fair average value for the gneiss. There are then 3.0×62.4 (wt. of 1 cu. ft. of water) or 188 lbs/cu ft, and 2000 lbs/188 lbs per cu ft, or 10.1 cubic feet per ton of gneiss. If 188 lbs/cu ft is multiplied by the number of cubic feet of gneiss under consideration and that value divided by 2000, the number of tons of gneiss is obtained. Multiplication of the average rare-earth content of the gneiss (value obtained from figure 11) by the number of tons gives the rare-earth content in tons.

In using figure 11 note that the three lines each have a different slope and represent trends for the samples as a whole. For example, consider the U-Thor 3 sample: for a total rare-earth content of 8.36 percent, ground radioactivity is about 0.2 mr/hr, phosphorus content is 0.73 percent, and thorium content is 0.39 percent. The points do not fall on each of the respective curves. Because of this one should not expect great accuracy in plucking values at random from the curves (rare-earth content as related to radioactivity especially). There are not enough points to strongly support the position of each line but still the trend is definite and important.

Rare-earth content obtained this way seems too high, and there are many variables to consider; too many to rely on this method for anything but the most general idea of the radioactive mineral content of the gneiss. A more precise determination of tonnage and tenor of the mineral reserves (marginal at present) must await further exploration. Exploration must involve diamond drilling to determine the extent in depth of mineralized Pinto Gneiss. The drill holes should be logged radiometrically and the cores analyzed chemically and mineralogically.

OUTLOOK

The future of these deposits depends mostly on the development of new uses for yttrium and its compounds. Current research by the U. S. Bureau of Mines should lead to new applications of yttrium and reduced costs of separating the metal from its sub-group associates, thus creating a new demand for the metal.

One of the most interesting and important potential uses of yttrium is in nuclear reactors. Because of its high melting point and low neutron capture cross-section it may be used in container materials for molten fuel in advanced reactors concepts (Geary, Guidoboni, and Lowenstein, 1962).

There are no quoted prices for xenotime concentrates and any sales of concentrates will have to be made by contract, which will no doubt stipulate a minimum percentage of yttrium and its sub-group lanthanides per ton. Dow Chemical Company and Lindsay Division of American Potash and Chemical Corporation are the major purchasers in the United States.

With additional exploration work in order to gain a better idea of reserves, and the consolidation of all the properties to be operated through one concern with one mill, the now marginal mineral material should be of important economic interest when a market develops.

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